Constraining the growth rate by combining multiple future surveys

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SKA SQUARE KILOMETRE ARRAY

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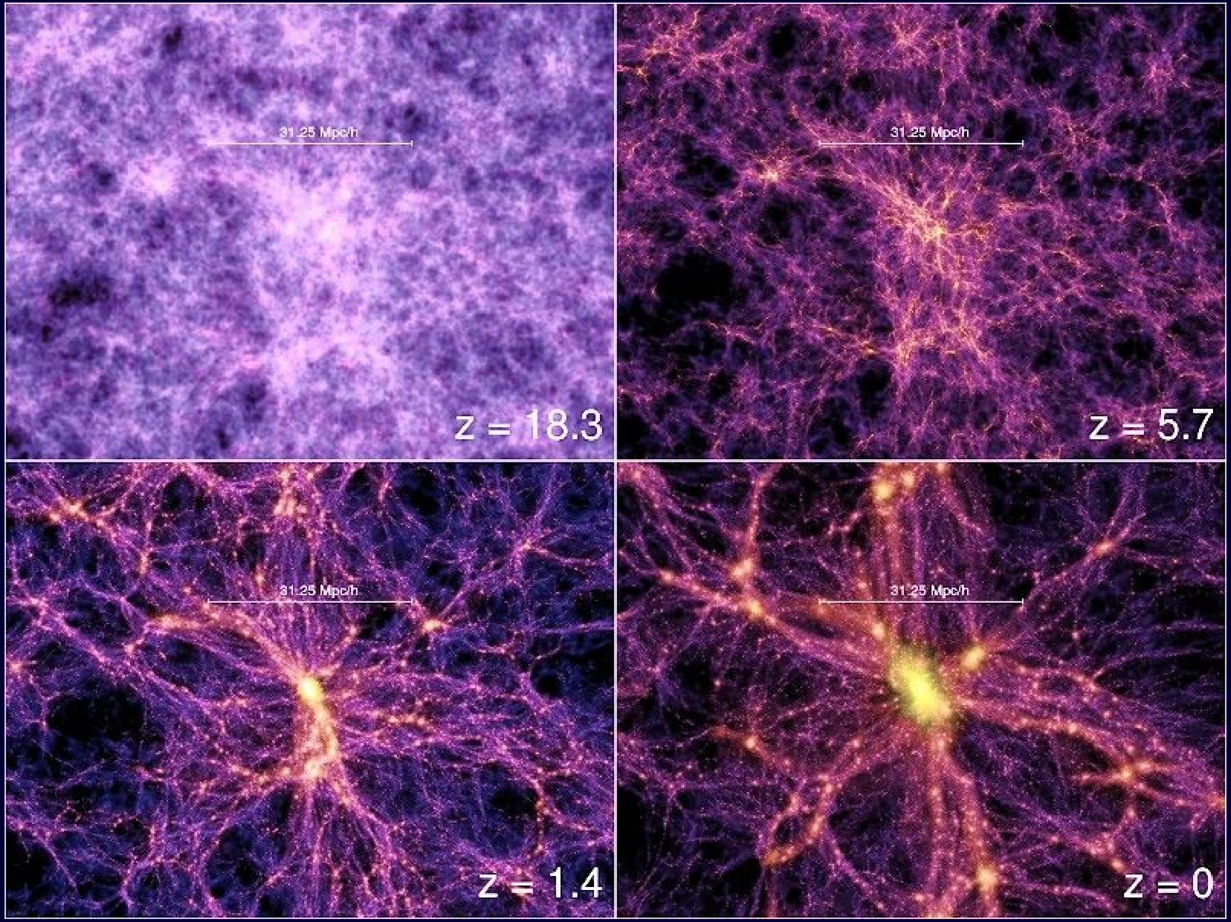
Large-scale structure formation

Primordial over/under-densities grow over time as a result of gravitational instabilities

The seeds of large-scale structure is observed as temperature fluctuations in the Cosmic Microwave Background

Using a cosmological model we evolve the initial conditions over time and reproduce the present day matter distribution



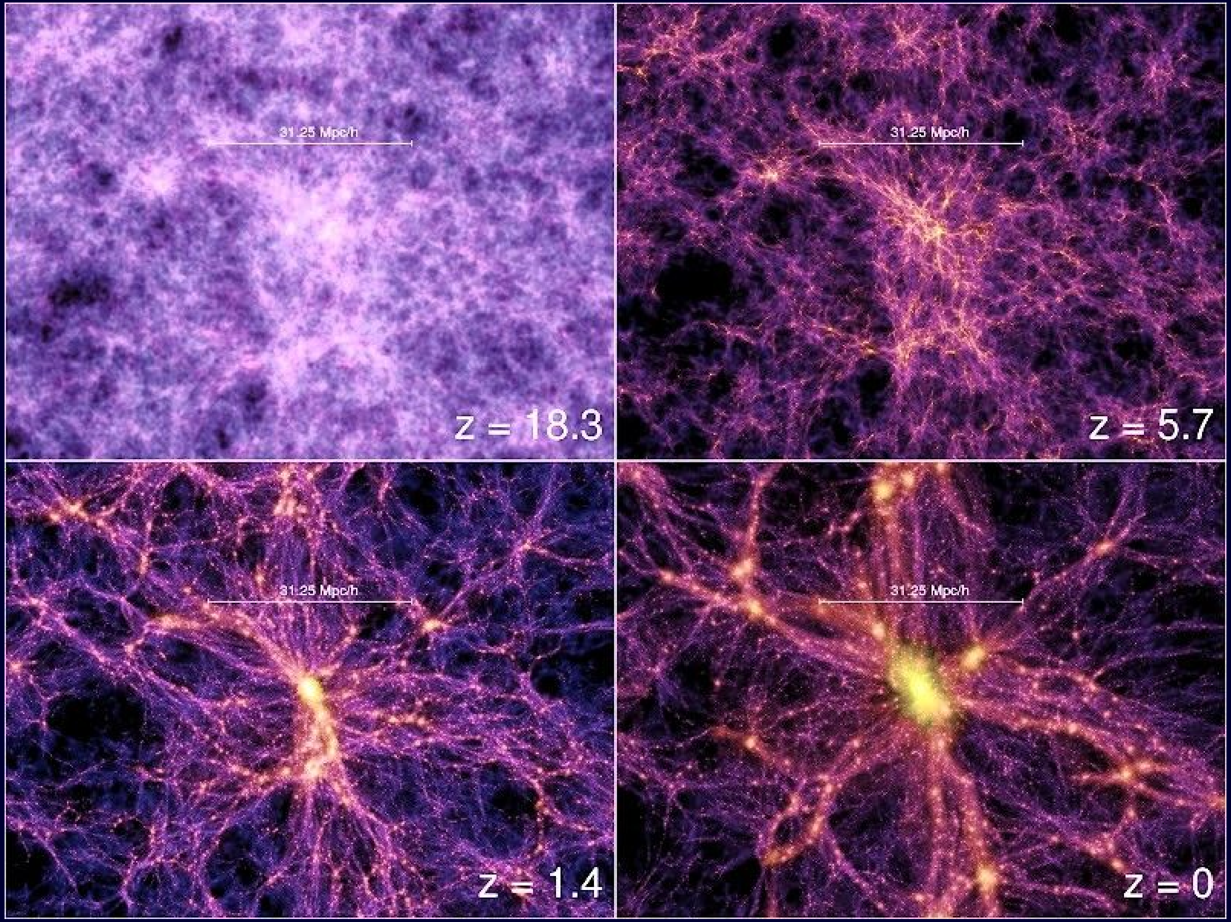
Large-scale structure formation

$$f = \frac{\partial \ln \delta}{\partial \ln a} = \Omega_{\mathrm{m}}^{\gamma}$$

- Growth rate provides a powerful consistency test of General Relativity and a test of Modified Gravity

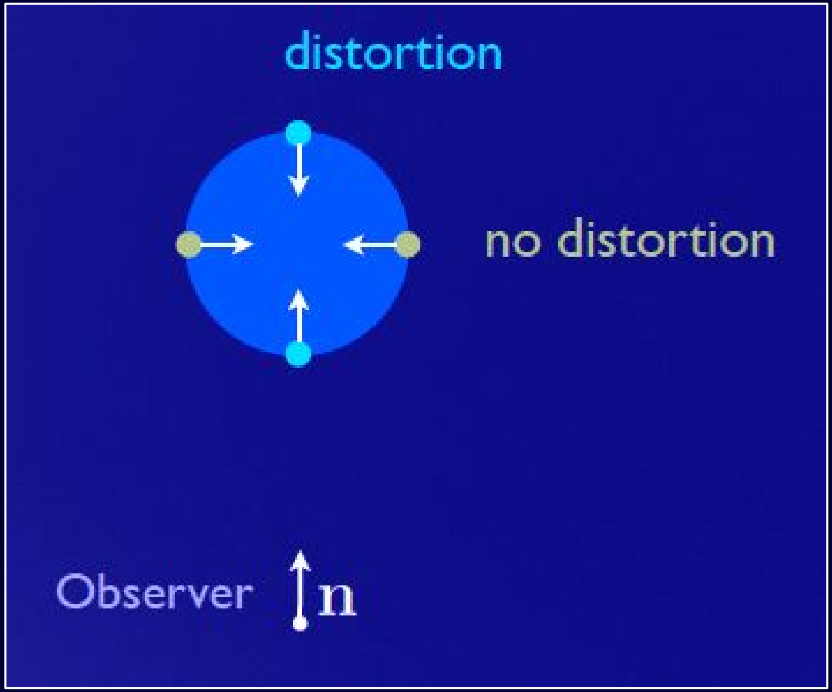
- $\gamma = 0.545$, for ΛCDM and standard DE models

- Growth rate extracted via RSD



Redshift Space Distortions

The peculiar velocity of a source induces a shift in the frequency of emission and therefore distorts apparent position in redshift space



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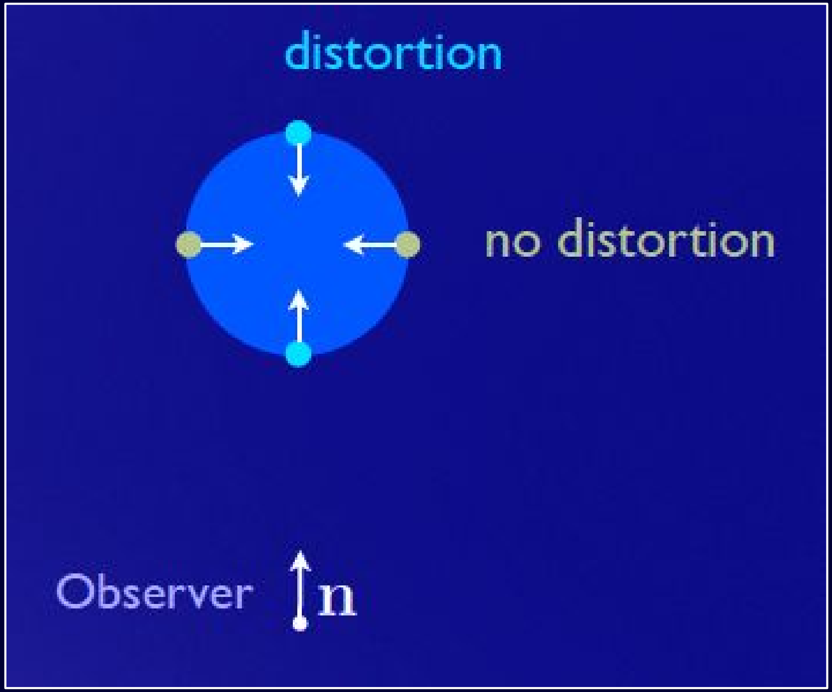
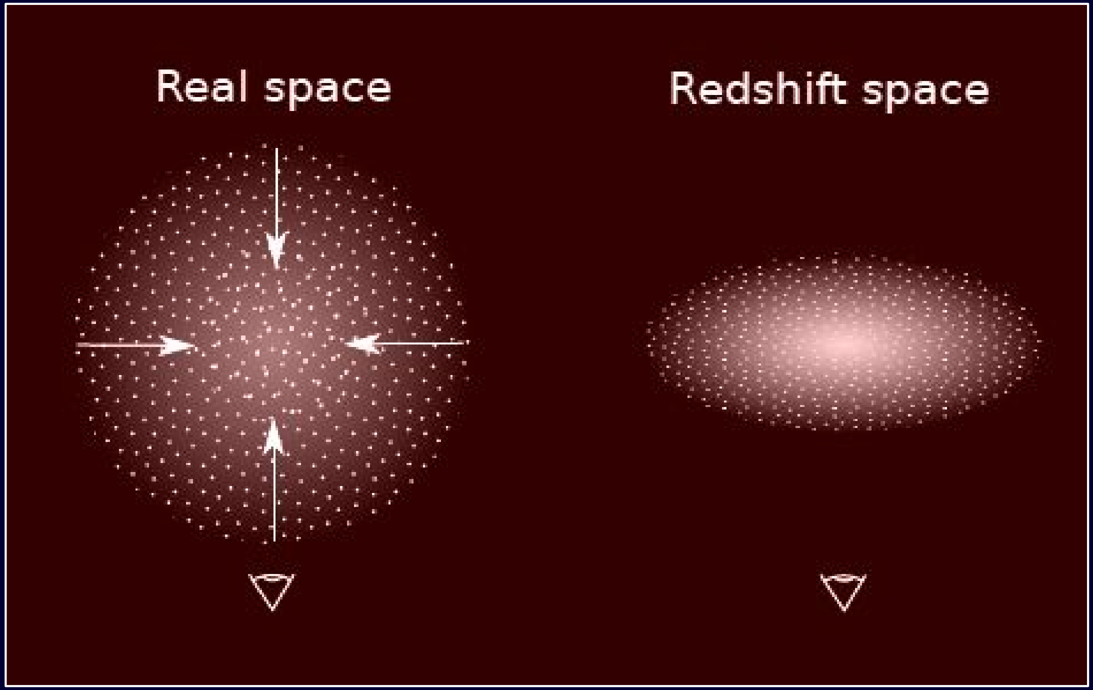
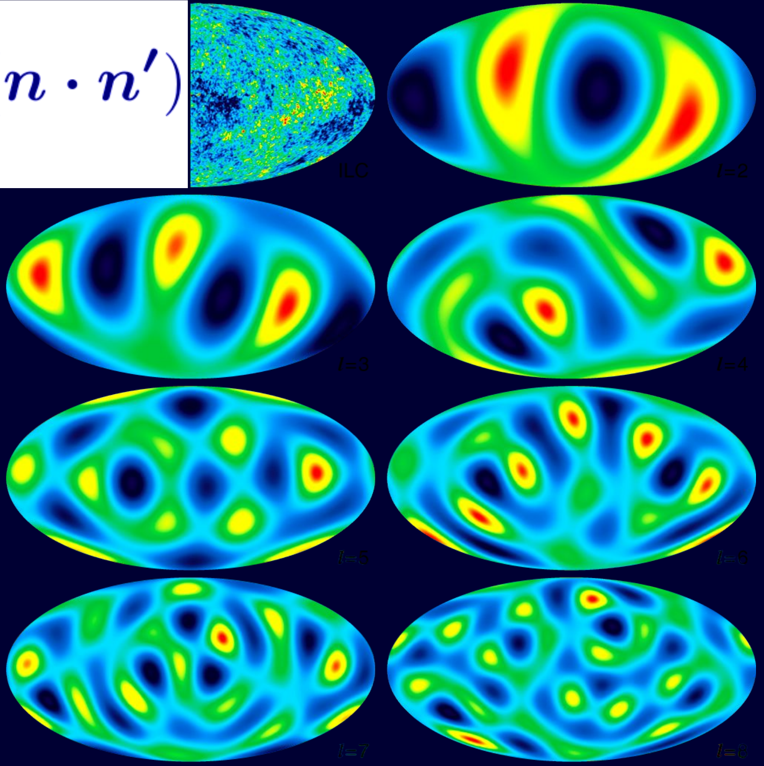




Observed galaxy power spectrum

Angular power spectrum is the spherical harmonic decomposition of the correlation function

$$\langle \delta_g(z, \boldsymbol{n}) \delta_g(z', \boldsymbol{n}') \rangle = \sum_\ell \frac{2\ell + 1}{2} C_\ell(z, z') \mathcal{L}_\ell(\boldsymbol{n} \cdot \boldsymbol{n}')$$



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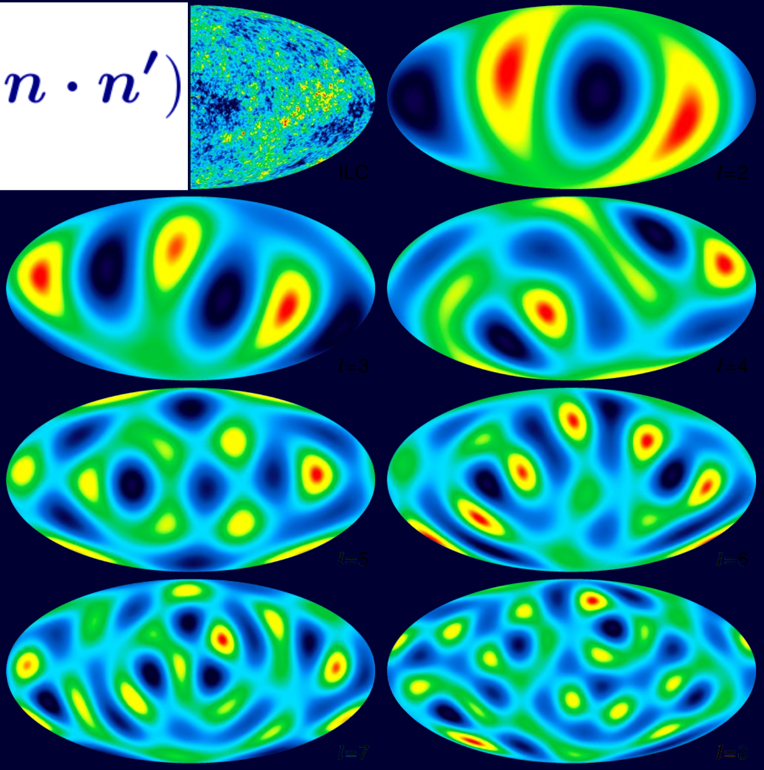
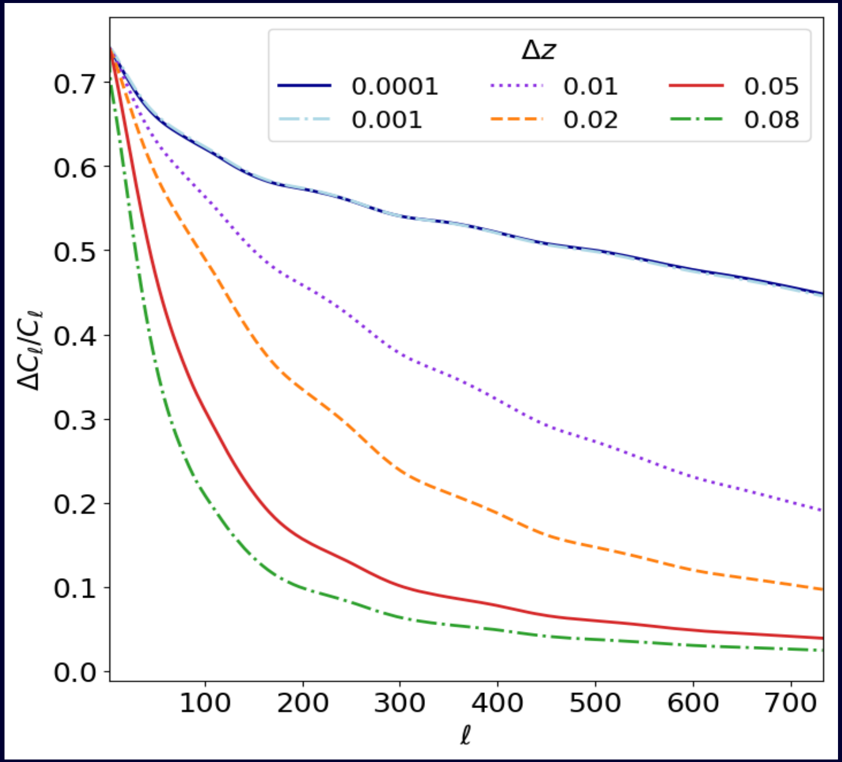


Unlike the Fourier space P(**k**,z):

- C_ℓ requires no fiducial model, hence no Alcock-Paczynski correction
- Naturally incorporates wide-angle effects and cosmic evolution
- Includes corrections from Doppler and lensing effects

Fractional contribution of RSD

- In wider redshift bins, peculiar velocities of galaxies are averaged out, hence RSD prefers thinner redshift bins
- Extracting RSD from power spectrum requires accuracy of spectroscopic redshift surveys



SKA IM (z=1)

Fisher forecast

$$F_{\vartheta_\alpha \vartheta_\beta} = \sum_{\ell_{\min}}^{\ell_{\max}} \frac{(2\ell+1)}{2} f_{\rm sky} \, {\rm Tr}\Big[(\partial_{\vartheta_\alpha} C_\ell) \Gamma_\ell^{-1} (\partial_{\vartheta_\beta} C_\ell) \Gamma_\ell^{-1} \Big]$$

Approximates the precision of measurement on cosmological paramaters assuming survey specifications and a cosmological model

$$\Gamma_\ell = C_\ell + N_\ell$$

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Cosmological model

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Cosmological model

Survey noise

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Cosmological model

Survey specifications

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Cosmological model

Survey specifications

$$\sigma_{\vartheta_\alpha} = \left[(F^{-1})_{\vartheta_\alpha \vartheta_\alpha} \right]^{1/2}$$

Constraint on cosmological parameter

Fisher forecast

$$F_{\vartheta_\alpha \vartheta_\beta} = \sum_{\ell_{\rm min}}^{\ell_{\rm max}} \frac{(2\ell+1)}{2} f_{\rm sky} \, {\rm Tr}\left[(\partial_{\vartheta_\alpha} C_\ell) \Gamma_\ell^{-1} (\partial_{\vartheta_\beta} C_\ell) \Gamma_\ell^{-1} \right]$$

Approximates the precision of measurement on cosmological paramaters assuming survey specifications and a cosmological model

$$\Gamma_\ell = C_\ell + N_\ell$$

Cosmological model

Survey specifications

$$\sigma_{\vartheta_\alpha} = \left[(F^{-1})_{\vartheta_\alpha \vartheta_\alpha} \right]^{1/2}$$

Constraint on cosmological parameter

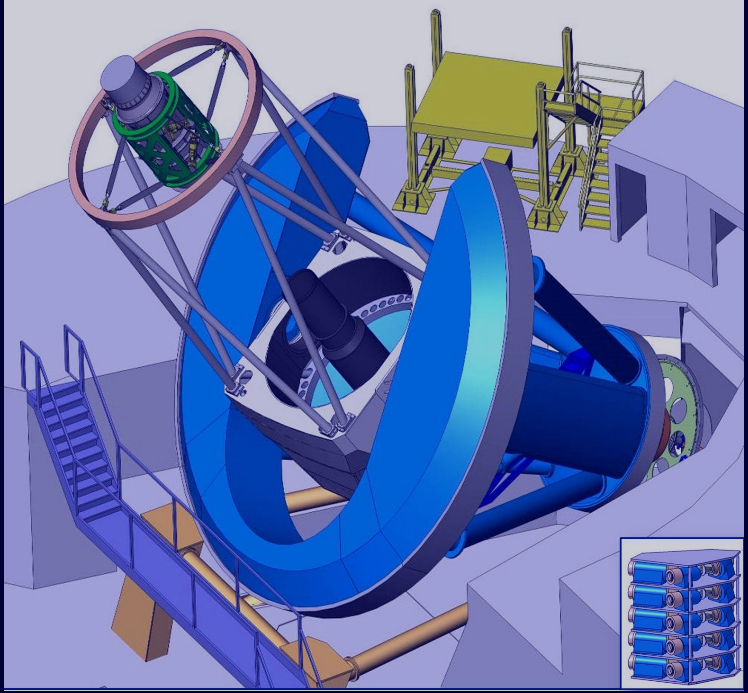
$$\vartheta_\alpha = [\ln \gamma, \ln A_s, b(z_i), \ln n_s, \ln \Omega_{m0}, w, \ln H_0]$$

Marginalised over clustering bias in each z-bin

Survey specifications

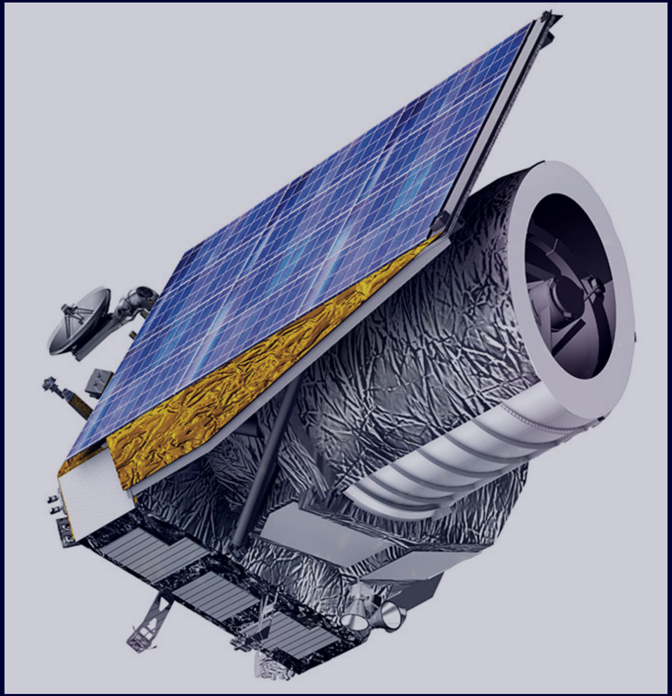
Next generation galaxy surveys:

Sky area - 15×10^3 deg^2



DESI (Bright Galaxy Sample)

$0.1 < z < 0.6$



Euclid (Hα)

$0.9 < z < 1.8$

Survey specifications

Next generation radio telescope: Square Kilometer Array (SKA)

Neutral Hydrogen Intensity Mapping using single dish configuration.

Sky area - 20×10^3 deg^2

SKA Mid 2:
$0.1 < z < 0.6$

SKA Mid 1:
$0.35 < z < 3.05$

Survey specifications

Next generation radio telescope: Square Kilometer Array (SKA)

Neutral Hydrogen Intensity Mapping using single dish configuration.

Telescope beam:

$$B_\ell = \exp\left[-\frac{\ell(\ell+1)}{16\ln 2}\theta^2_{\rm res}\right]$$

Sky area - $20\text{x}10^3$ deg^2

SKA Mid 2:
$0.1 < z < 0.6$

SKA Mid 1:
$0.35 < z < 3.05$

Combining surveys

Observations in different frequency ranges create complementary sets of dark matter tracers.
The multi-tracer technique includes auto- and cross-spectra.

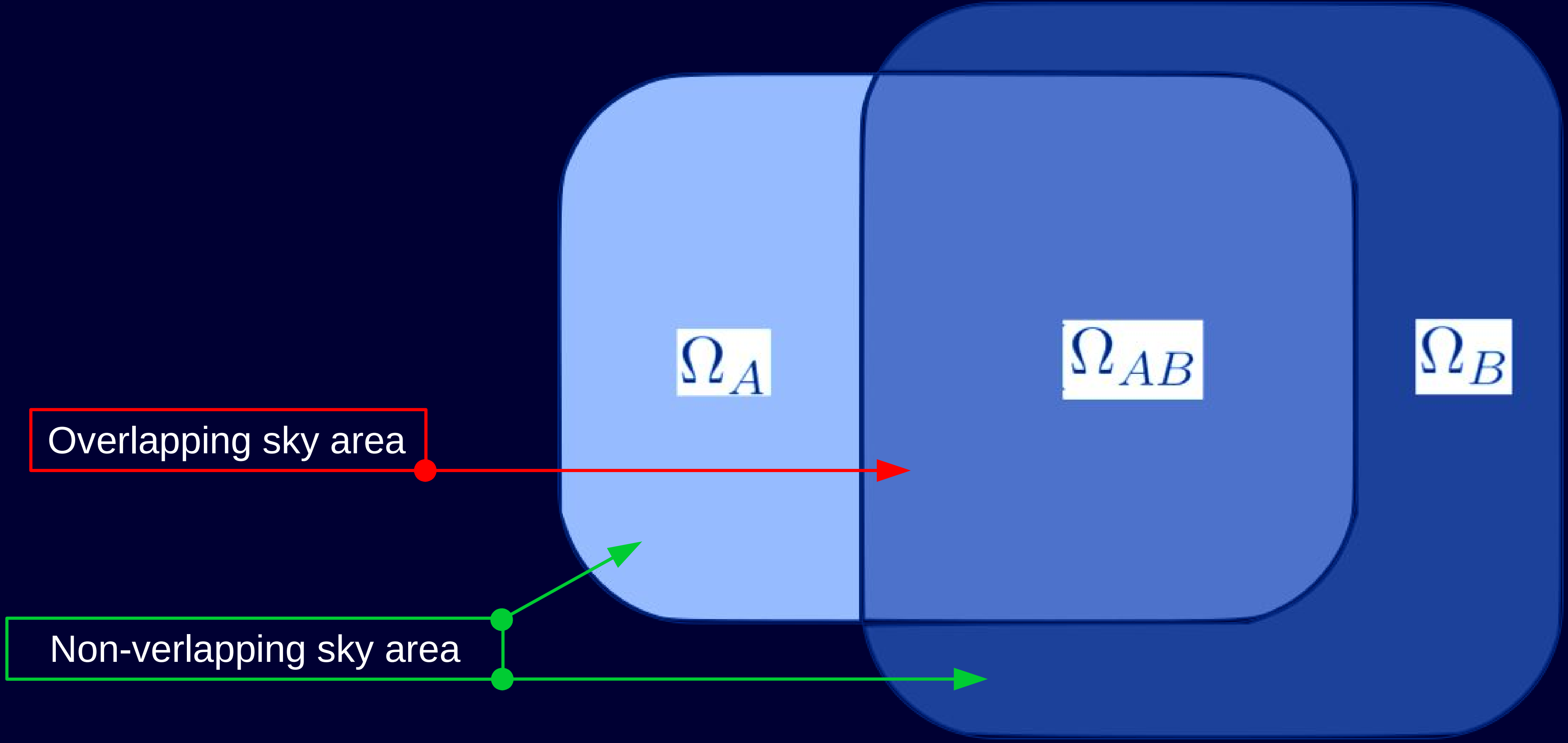
$$\langle \delta_g^A(z_i, \boldsymbol{n}) \delta_g^B(z_j, \boldsymbol{n}') \rangle = \sum_\ell \frac{2\ell+1}{2} C_\ell^{AB}(z_i, z_j) \mathcal{L}_\ell(\boldsymbol{n} \cdot \boldsymbol{n}')$$

Multi-tracers:

- Suppress systematics
- Reduces cosmic variance
- Therefore improve constraints

$$C_\ell^{AB}(z_i, z_j) = \begin{bmatrix} C_\ell^{\mathrm{HI,HI}} & C_\ell^{\mathrm{HI,GS}} \\ C_\ell^{\mathrm{GS,HI}} & C_\ell^{\mathrm{GS,GS}} \end{bmatrix}$$

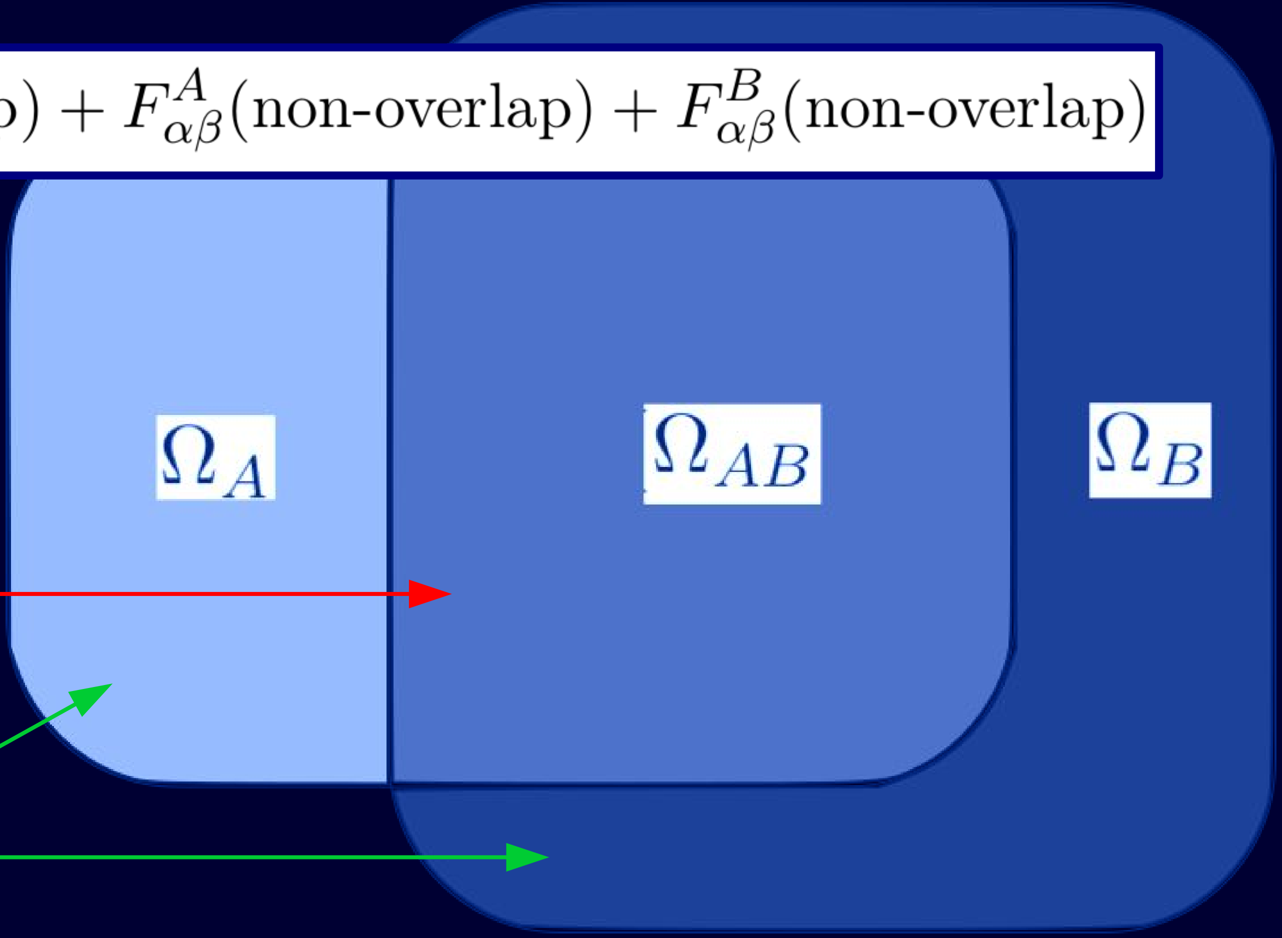
Total observed volume



Total observed volume

$$F_{\alpha\beta}(\text{total}) = F^{AB}_{\alpha\beta}(\text{overlap}) + F^{A}_{\alpha\beta}(\text{non-overlap}) + F^{B}_{\alpha\beta}(\text{non-overlap})$$

The largest observable scales are reduced in each region

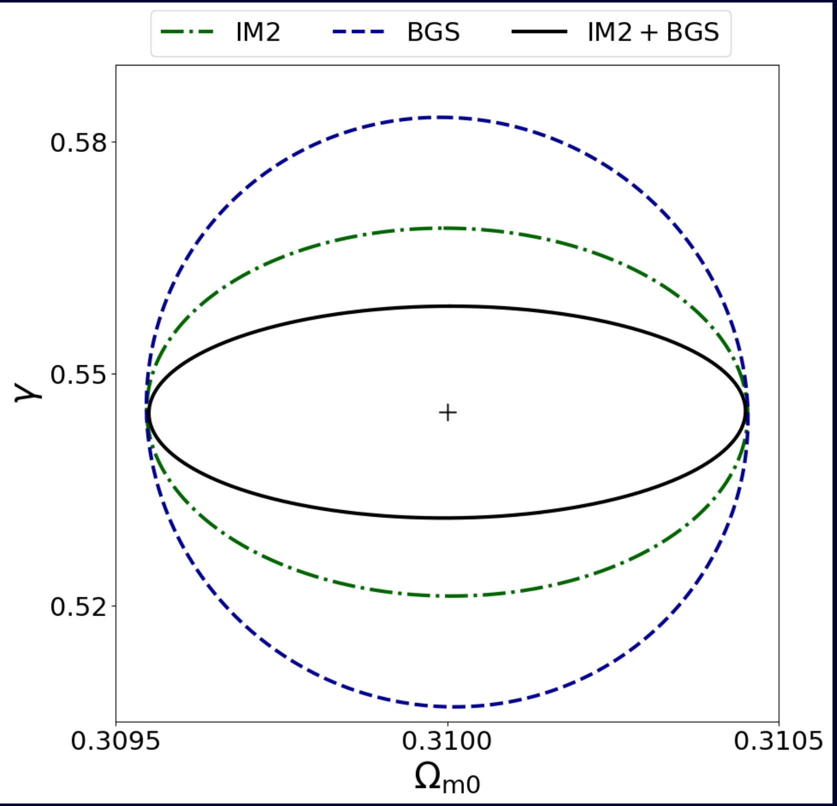


Assume overlapping sky area: 10^4 deg^2

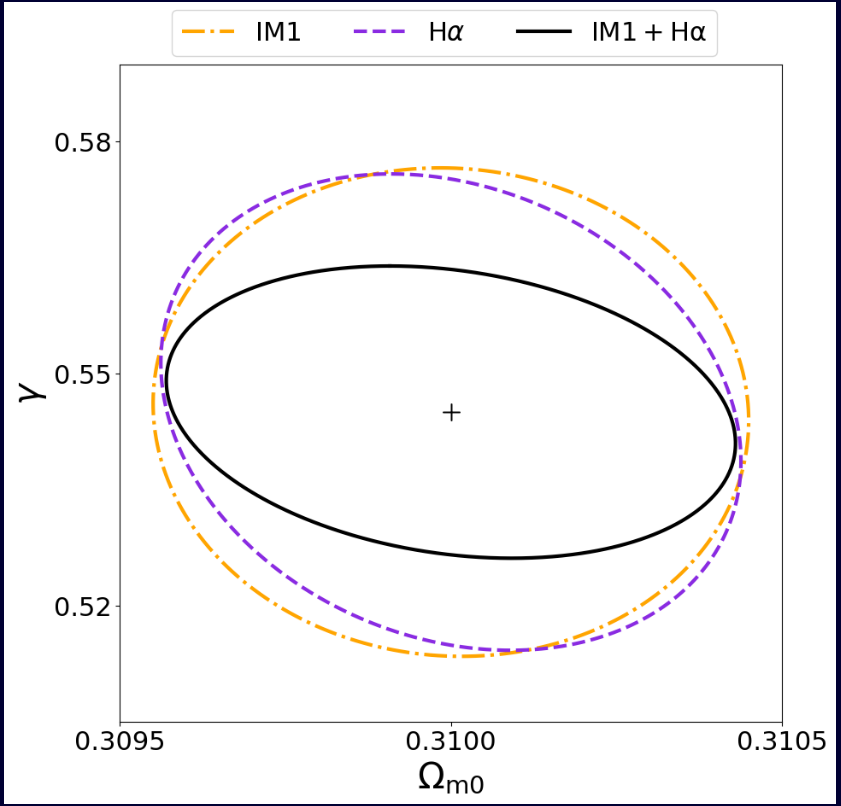
Non-verlapping sky area

Combined results

1σ-contour plots

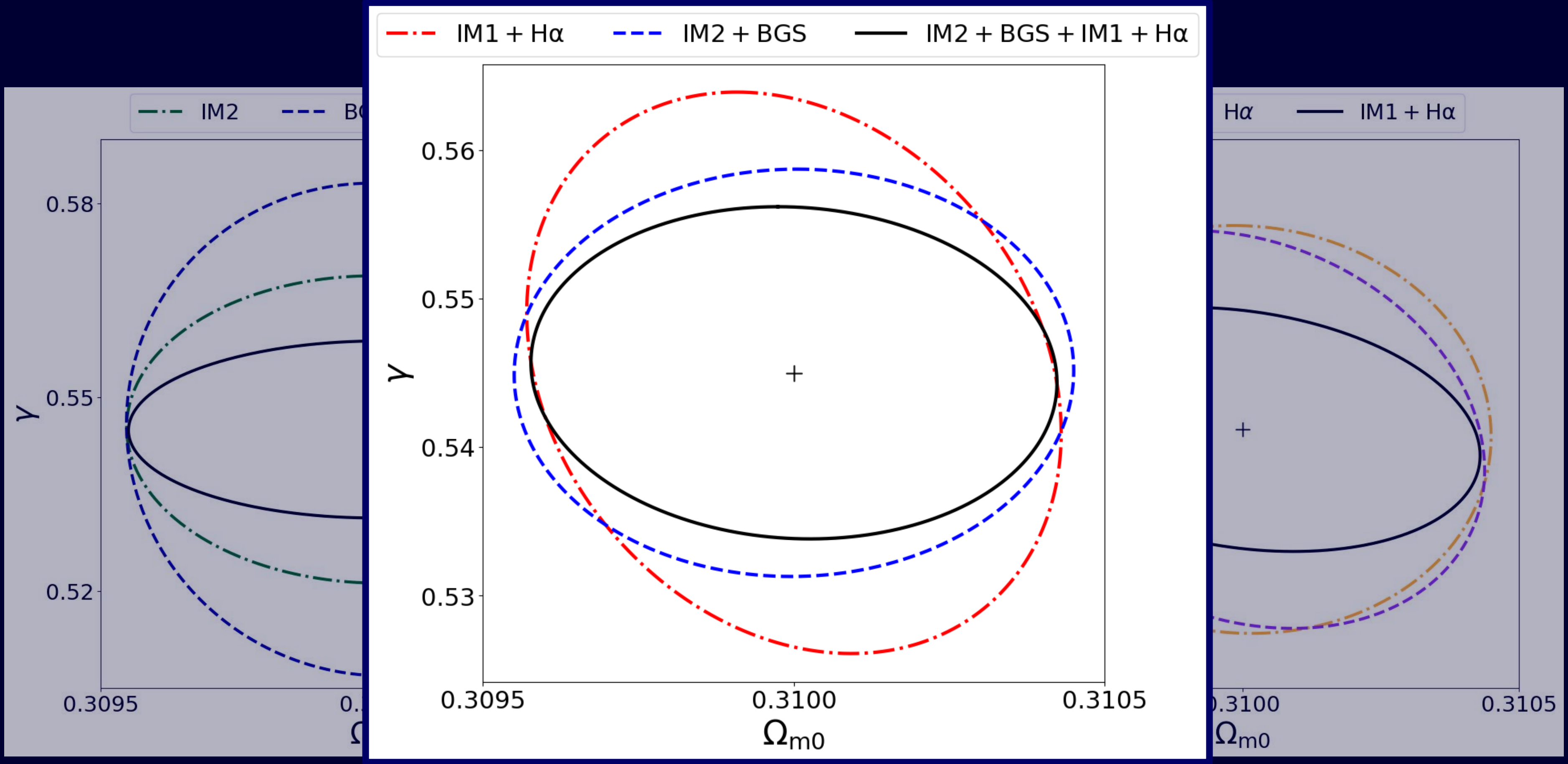


Low redshift (0.1 < z < 0.6)



High redshift (0.35 < z < 3.05)

Combined results



Combined redshift: 0.1 < z < 3.05

Summary

Constraints computed using only linear scales

	Survey	$\sigma_{\ln\gamma}$ (%)
Low redshift	BGS	4.7
	SKA1 IM2	2.9
	Combined total: IM2+BGS	1.6
High redshift	Hα survey	4.0
	SKA1 IM1	3.8
	Combined total: IM1+Hα	2.3
Low + High redshift	Combined total: IM2+BGS+IM1+Hα	1.3

Redshift bin-width: Δz=0.01

Summary

Constraints computed using only linear scales

Best result from single tracer

	Survey	$\sigma_{\ln\gamma}$ (%)
Low redshift	BGS	4.7
	SKA1 IM2	2.9
	Combined total: IM2+BGS	1.6
High redshift	Hα survey	4.0
	SKA1 IM1	3.8
	Combined total: IM1+Hα	2.3
Low + High redshift	Combined total: IM2+BGS+IM1+Hα	1.3

Redshift bin-width: Δz=0.01

Combining surveys improved constraints up to ***55%***